



# Geo-environmental characterization of Pusan clays at Hwajeon site

**Rao KG**

Post-Doctoral fellow, Dept. of Civil Engineering, Dong-A University, Busan, South Korea; Email: reach.drkg Rao@gmail.com

## Publication History

Received: 13 July 2015

Accepted: 26 August 2015

Published: 1 October 2015

## Citation


Rao KG. Geo-environmental characterization of Pusan clays at Hwajeon site. *Discovery*, 2015, 41(186), 1-7

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## General Note

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## ABSTRACT

Pusan clays are deposited along the Nakdong River delta. In order to develop new land for both industrial and residential use, Korean government has done land reclamation works to meet the land requirement. In Nakdong River delta, the depositional environment is slightly different in every locality. In this study, an attempt has been made for the geo-environmental site characterization of Pusan clay at one area, hereafter called as "Hwajeon", which is along the Nakdong River estuary, where a series of field and laboratory tests were carried out. The results from the cone penetration tests (CPT) are used to stratify the Pusan soft clays. In addition to this, laboratory geological study was carried out to derive site specific geological depositional environments. The results obtained from both field and laboratory investigation are compared and used for the geo-environmental characterization of the Pusan clays at the Hwajeon site. As a result of the study, it was found that the clays could be classified as soft, cemented, young, and normally consolidated clays. It was found that, the Pusan clays, of Holocene age, can be largely divided into two major sedimentary units due to different depositional environment. The geological analysis results indicated that the main clay minerals illite and kaolinite. The variation of the physical and mechanical properties with depositional environment of the Pusan clays were much better evaluated.

**Keywords:** Pusan clay, geology, geotechnical properties, depositional environment, Characterization.

## 1. INTRODUCTION

A thick clay deposit unusually covers the Nakdong River delta, which lies west of Busan City in Korea. The clay, which is called Busan (or Pusan) clay, sometimes reaches a maximum of 70 m thick. Since the early 1990s, a number of ground investigations have been carried out based on a routine local practice for several huge projects such as a new port, industrial and residential complexes, and others. Such investigations were extremely insufficient to clarify the geotechnical characteristics even in a limited area (Chung *et al.*, 2002b, 2003). This resulted in the highly underestimation of the settlement (Chung, 1999) and failure of the breakwater (Chung *et al.*, 2006b), which are typical examples of unacceptable evaluations of the geotechnical properties in the area. Thereafter, a comprehensive investigation was conducted, which involved high quality undisturbed sampling, geological investigation, and other field and laboratory tests. In this study, importance is equally given for geological investigation so as to better understand the variations in depositional history in the delta (Chung *et al.*, 2002c, 2003; Ryu *et al.*, 2005). However, most of the investigations were largely performed along the coastlines of the delta (Chung *et al.*, 2005, 2006a, 2007, 2010). Thus, to evaluate the effects of different depositional environments in the localities, there is a need to conduct such investigations exclusively in as many locations as possible in the delta area and to correlate between the geological and the geotechnical characteristics. The purpose of this study is to characterize the study area through the both geological as well as geotechnical characteristics of the clay. In order to achieve this, a comprehensive geological and geotechnical investigation is carried out at the study area, where there is a plan to develop residential and industrial facilities. The investigation includes an advanced sampling technique, field tests such as boreholes and CPT tests, and laboratory tests for both physical and mechanical properties of the soil. The soil stratification has been carried out using the CPT result. Variations in the index properties and some mechanical properties of the soil are used to determine their relationship with the depositional environment.

### 1.1. Site Location

In the present study, a vast coastal area along the Nakdong river has been taken, which is locally called as "HWAJEON" which is shown in the Figure-1 along with other adjacent sites (hereafter referred as Hwajeon site). The Hwajeon site is significantly large with an area of about 2.4km<sup>2</sup> and exactly located along the bank of the Nakdong river as shown in the Figure-1 below.



**Figure 1** Location of study area

## 2. PROPOSED EXPERIMENTAL PROGRAM

An experimental program was planned in such a way that all necessary soil parameters can be obtained across the study area. The testing program includes possible in-situ and laboratory tests. All in-situ tests are carried out as close as possible to the proposed Boreholes at the site. Separate boreholes have been explored for geological study, which are proposed close to the boreholes explored for geotechnical study so that the variation of the geotechnical properties can be compared with geological profiles.

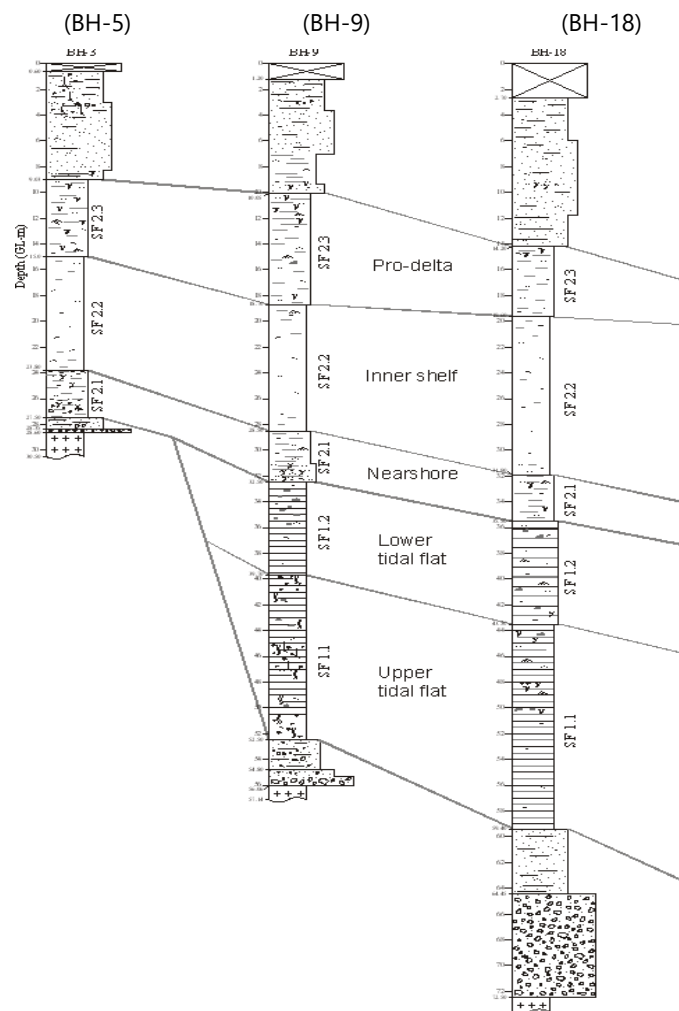
### 3. GEOLOGICAL CHARACTERISTICS

#### 3.1. General

The Nakdong River delta, which lies west of Busan City and its vicinities, is covered with very thick clay that sometime reaches a maximum thickness of 70 m. The deltaic area is divided into four categories (upper and lower delta plains, floodplain, and delta-front or pro-delta) according to physiography (Kwon 1973; Kim 1988). Tested site is situated in the floodplain (i.e., marginal basin) which is in the west and middle of the plain.

#### 3.2. Depositional Environment Investigated at BH-5, BH-9 and BH18

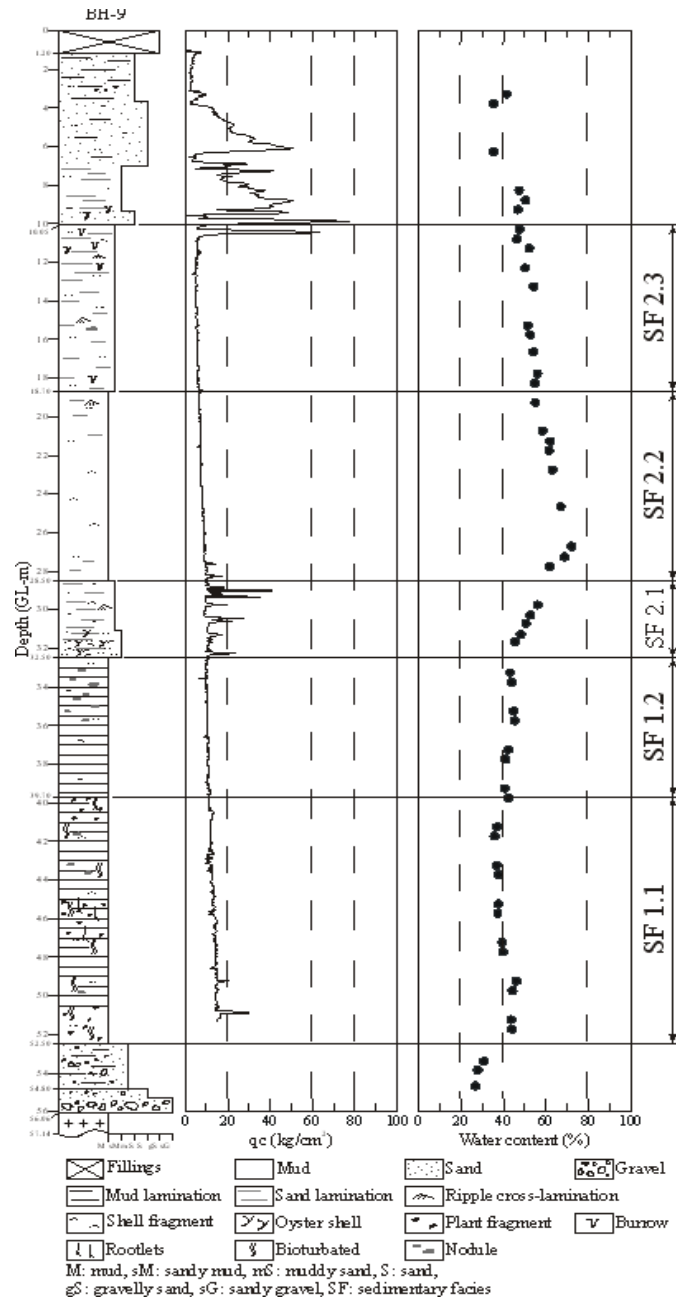
A comprehensive geological investigation was performed on the undisturbed samples obtained from BH-05, BH-09 and BH-18 and the results obtained are presented in the Fig. 2 below. The Late quaternary deposits at the location consist of two sedimentary units in ascending order: SF1 and SF 2 as shown in the Fig.2 below. The presented geological profile at BH-05 indicates that the lower sedimentary unit (SF1) is not present whereas both SF1 & SF2 are present at BH-09 as well as BH-18 though the thickness of each unit varies across the site. It is also observed that each sedimentary unit is further subdivided into sub-sedimentary units as show in the Fig.2 below. The lower sedimentary unit (SF1) is made up of soft massive mud that has been formed at Tidal Flat (TF). SF1 has been sub-divided into SF1.1 and SF1.2 based on upper tidal and lower tidal respectively. The Sedimentary unit (SF2) is made up of soft, shelly massive mud that has been formed in a near-shore, inner-shelf and pro-delta, which are subdivided as SF2.1, SF2.2 and SF2.3 respectively, as shown in Fig.2 below. The top about 10m of soil has been classified as silty sand/sand and relatively young, hence more importance was not given in this study while evaluating the geological sedimentary units.



**Figure 2** Results from geological investigation for the study area

#### 4. GEOTECHNICAL CHARACTERISTICS

In order to evaluate the geotechnical properties with respect to the geological depositional environments, field tests (CPT and Boreholes (BH-3, BH-4, BH-9, BH-14 & BH-18)) and laboratory tests for soil index parameters were conducted on the samples obtained from all the boreholes explored at the study area (Chung, S. G et. al.). Cone resistance ( $q_c$ ) and index soil parameters from the laboratory test results, such as soil unit weight ( $\gamma_t$ ), natural moisture content (Wn), Plastic limit (PL), Liquid Limit (LL), and Specific gravity (Gs) are used to evaluate the dependency of the geotechnical properties on the geological depositional environment. The thickness of the clay layer, below the top sand bed, is varying from about 20m to 45m.



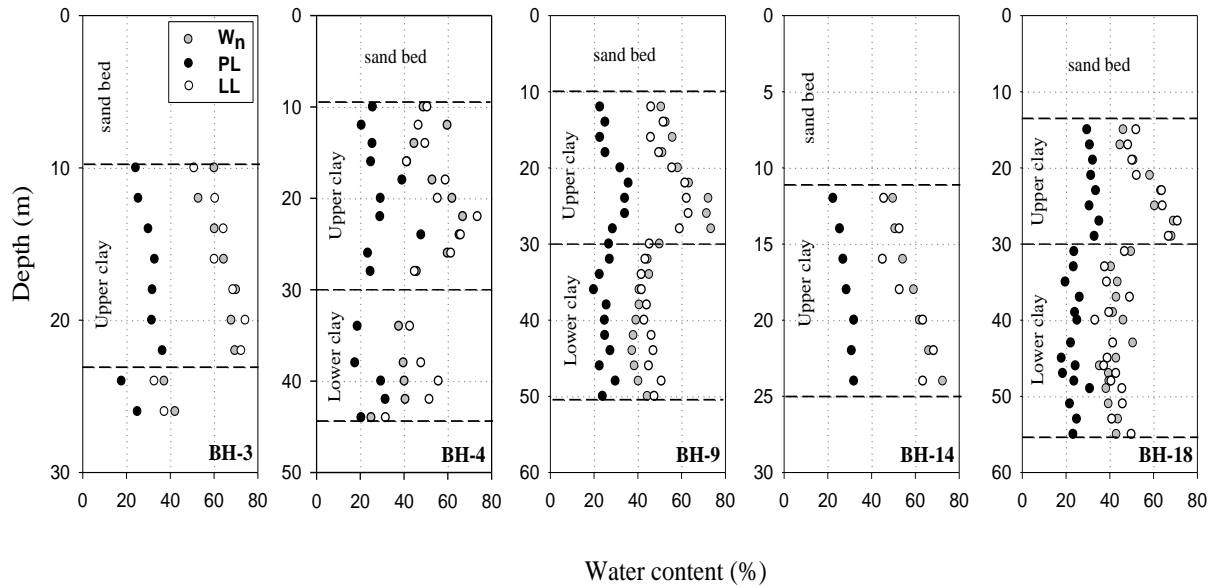
**Figure 3** Combined soil profile showing the geological as well as geotechnical properties

##### 4.1. Variation of Geotechnical Properties with Depositional Environment

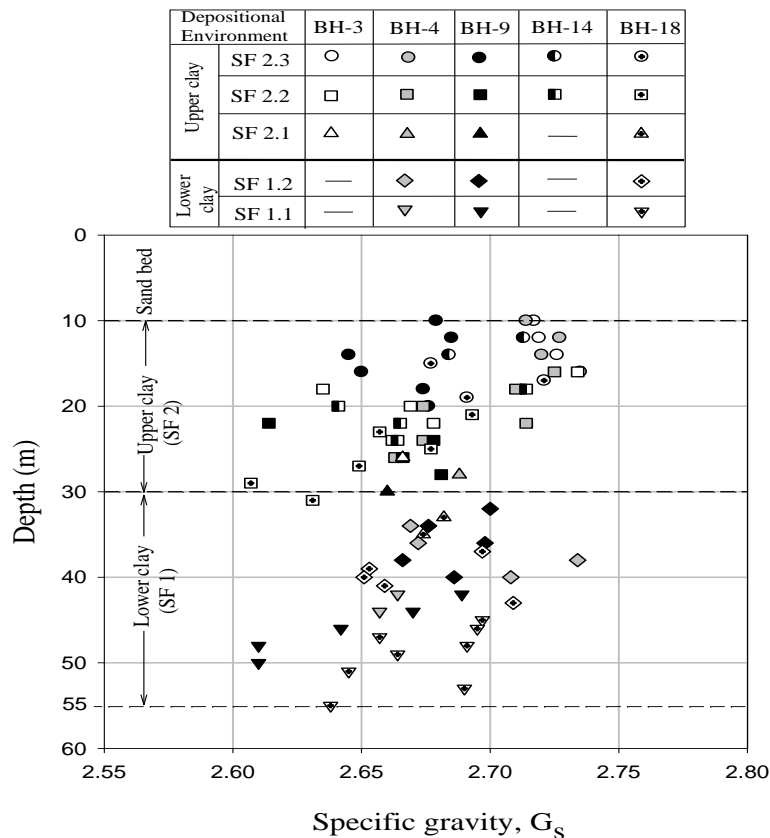
Figure 3 shows the variation of CPT cone resistance ( $q_c$ ) as well as the natural moisture content (Wn) with depth along with geological depositional environment profile. It can be clearly noticed that the variation of soil mechanical property (i. e  $q_c$ ) and index property (i. e Wn) are significantly depending on the geological sedimentary units, SF1 and SF2. Hereafter, SF1 and SF2 are referred

as “Lower Clay” and “Upper Clay” respectively. Upper clay thickness is about 20m (i. e from 10m BGL to 30m BGL), whereas lower clay thickness is about 25m (i.e from 30m BGL to 55m BGL)

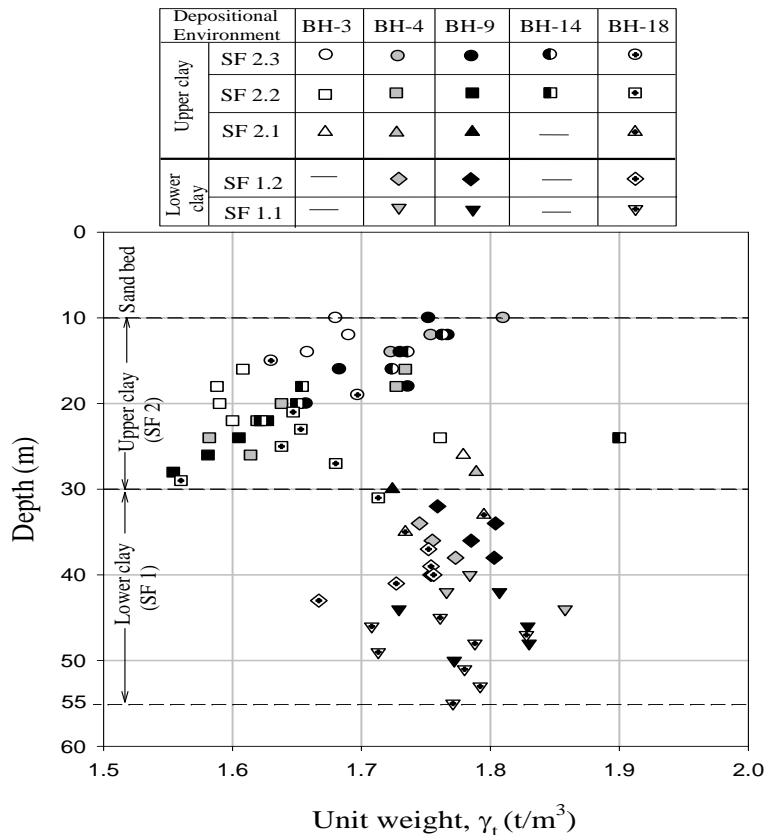
Figure 4 shows the variation of moisture content with depth in both upper and lower clay. It can be clearly noticed that the moisture content is little higher in the upper clay compare to the in lower clay. The moisture content increase in the upper clay from 45% to about 65% and then a significant drop is observed at the interface between upper and lower clays, then almost remains constant in the lower layer, with slight variation. Figure 5 shows the variation of specific Gravity ( $G_s$ ) with depth in both upper and lower clays. It can be noticed from  $G_s$  profile that there is clear separation between the upper and lower clays. Though there is scatter in the  $G_s$  data, the order remains almost same for both upper and lower clays. In both the layer  $G_s$  is decreasing with depth.



**Figure 4** Variation of water content ( $W_n$ ), Liquid Limit (LL) and Plastic Limit (PL) with depth



**Figure 5** Variation of Specific gravity ( $G_s$ ) with depth



**Figure 6** Variation of Unit Weight ( $\gamma_t$ ) with depth

Figure 6 shows the variation of unit weight ( $\gamma_t$ ) with depth in both upper and lower clays. It is very interesting to notice that the variation is very clear and is much different in each layer. Unit weight in the upper clay is decreasing from about 1.8 t/m<sup>3</sup> to about 1.55 t/m<sup>3</sup> with significant variation within this layer. Whereas, unit weight in the lower layer is almost remains constant within the range between 1.7 t/m<sup>3</sup> and 1.85 t/m<sup>3</sup>.

## 5. CONCLUSION

Based on the above study, the following conclusion may be arrived:

1. CPT test results are recommended to be used to stratify the soil layers
2. It is observed that there is close relation between geological and geotechnical characteristics
3. The geotechnical properties have well defined trends distinguishing different geological sedimentary units at Study area.
4. It is recommended to use geological investigation along with geotechnical investigation to evaluate the better characterization the soils.

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